Information extracted from:

National Academies of Sciences, Engineering, and Medicine 2020. Airborne Transmission of SARS-CoV-2: Proceedings of a Workshop in Brief. Washington, DC: The National Academies Press. https://doi.org/10.17226/25958

The workshop was organized by the *Environmental Health Matters Initiative (EHMI)* to address the state of the science (what is known and what research is needed). It covered the latest scientific evidence about airborne transmission of SARS-CoV-2 and discussed critical research gaps to inform prevention policies. The included experts ranged from different disciplines including aerosol and atmospheric science, virology, infectious disease, and epidemiology.
Questions that were considered were:

1. **HOW IS CONSIDERATION OF SARS-COV-2 TRANSMISSION AS EITHER RESPIRATORY DROPLETS OR AEROSOLS SUPPORTED BY THE SCIENCE?**
   Transmission of respiratory viruses can occur through direct person-to-person contact, indirect contact, large droplet spray, aerosols, or a combination of these.

   Droplets are sprayed on to the body and its mucus membranes, a form of contact transmission, while aerosols are inhaled into the respiratory system. This distinction currently drives control strategies, infectious dose, and severity of disease. At close range, both contact and inhalation transmission routes are possible, but at a longer range, once droplets have settled quickly, **transmission by inhalation is the important route**. Aerosol science indicates there is no 5 µm "cutoff," so aerosols >5 µm spread further than 6 feet and are subject to inhalation. These aerosols and droplets are produced by breathing, talking, and coughing, with talking associated with aerosols and the fast-settling droplets with coughing.

TABLE 1 Terminology for Particles Involved in Airborne Diseases

Terms	Traditional Thinking (based on longstanding misconceptions, *not* informed by aerosol science)	Updated Descriptions (informed by aerosol science and exposure pathways)		
		Definition and Typical Size	Behavior in Air	Exposure Pathways
Aerosol[a]	Particle <5 µm	Stable suspension of solid and/or liquid particles in air, smaller than about 100 µm	Can remain airborne for extended time. Concentration is highest near source. Concentration decreases with distance from source but can travel farther than about 2 meters or 6 feet and build up in a room	Inhaled into respiratory system
Droplet	Particle >5 µm	Liquid particle, larger than about 100 µm	Settles quickly to the ground or on to a surface. Travels less than about 2 meters or 6 feet, except when propelled (e.g., sneezes and coughs)	Exposure via eyes, nose, or mouth at close range

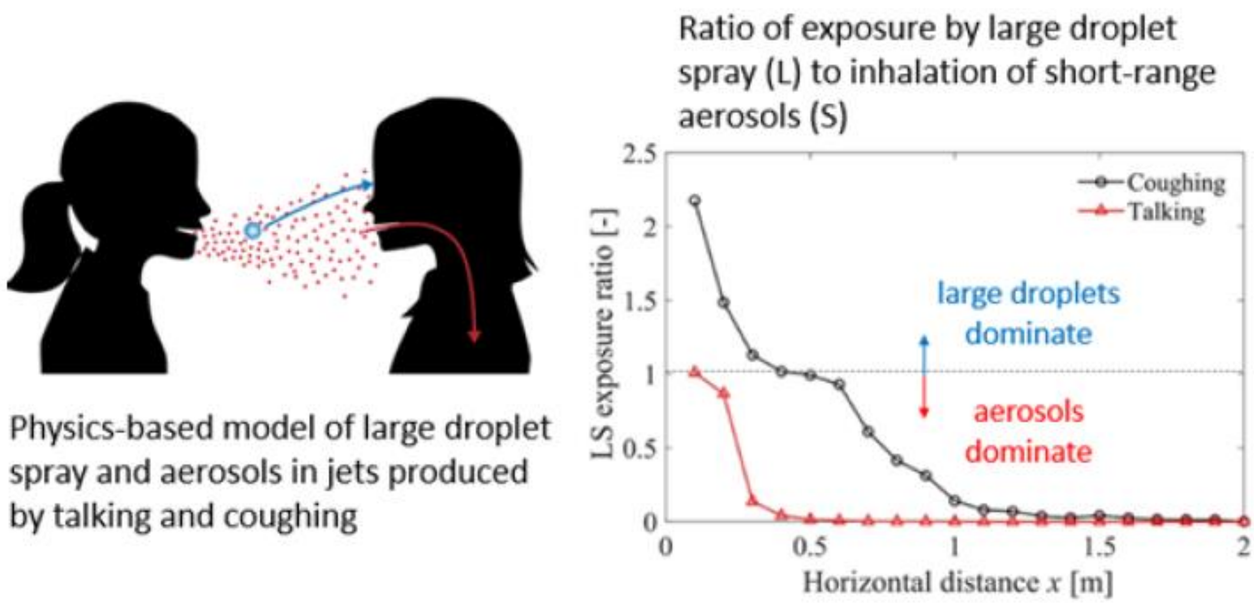
[a] Aerosol is used here as a shorthand for "aerosol particle," reflecting common usage. When the physical attribute of the particle is described in this document, the term aerosol particle is used.

Notes: The table illustrates how differences in language can contribute to confusion and prevent a shared understanding of the science. Several workshop leaders proposed terminology informed by aerosol science and emphasizing exposure path to improve communication and understanding. This table was based on concepts presented by Linsey Marr and others at the workshop. Reprinted from Airborne Transmission of SARS-CoV-2: Proceedings of a Workshop in Brief, by National Academies of Sciences, Engineering, and Medicine,2020, retrieved from http://nap.edu/25958

2. WHAT SIZE DROPLETS AND AEROSOLS ARE GENERATED BY PEOPLE AND HOW DO THEY SPREAD IN AIR?

Individuals generate aerosols and droplets across a wide range of sizes and concentrations. The size distribution is multimodal, reflecting the origin of aerosols and droplets in different regions of the respiratory tract and production via different mechanisms. Most aerosols observed in human breath are <10 µm. Breathing, talking, and singing produce ~100–1,000× more aerosol particles (<100 µm) than droplets (>100 µm).

Aerosol production varies widely for different people and activities (e.g. louder talking produces a larger number of aerosols than softer talking or whispering. Activities that involve deeper breathing (e.g., singing) produce more aerosol particles from the lower respiratory tract).



Note: This figure was produced by Chen et al. 2020, and it showed the differences between droplets versus aerosols during coughing and talking. Aerosols dominate as the distance from the source increases, for both coughing and talking related exposure. From "Airborne Transmission of SARS-CoV-2: Proceedings of a Workshop in Brief", by *National Academies of Sciences, Engineering, and Medicine,2020, Washington, DC: The National Academies Press*, p.6(https://doi.org/10.17226/25958). Copyright 2020 by National Academy of Sciences.

Supported lines of evidence reporting that **aerosols represent an important transmission pathway for SARS-CoV-2**:

- Aerosols can contain infectious SARS-CoV-2, remain suspended in air for hours, and be transported many meters from the source.
- Asymptomatic individuals emit mostly aerosols with sizes <10 µm and produce very few droplets.
- Super-spreading events are more readily explained by aerosol transmission.
- Aerosols are more concentrated at close range and can spread and accumulate in a room, leading to both close and long-range exposure.
- Transmission in outdoor settings has been much less common than indoors.

As more studies had emerged evidencing airborne transmission as a potential pathway, **what kind of interventions to minimise the spread of SARS-CoV-2 can be applied?**

a) Use of masks, which limits bidirectional transfer of infectious aerosols and droplets, protecting the wearer and those surrounding the wearer. Available evidence for face coverings (masks) consistently indicates a reduction of community transmission.

b) Maintaining distances, even on indoors activities, because of local leakage from the masks and accumulation of aerosols indoors.
c) Ventilation and filtration have a major effect on aerosol concentrations.
d) Plexiglass barriers and face shields reduce droplet transmission, but do not limit aerosols because they are transported in the air currents.

3. WHICH SIZE DROPLETS AND AEROSOL PARTICLES ARE INFECTIOUS AND FOR HOW LONG?

Viral half-life in aerosol is approximately **1.1 hours** (van Doremalen *et al.* 2020).

UV light greatly decreases virus stability, and lower temperatures and humidity may increase stability (Schuit *et al.* 2020). On studies showing the effect of sunlight in simulating UV light-scenarios of three different stations of the year, reported that the half-life of SARS-CoV-2 decreased to less than 6 minutes, or 10% of what is seen in dark environments.

Reported challenges in studying and understanding ***the dose required for infection***:

a) Characterization of human-generated infectious SARS-CoV-2 aerosols;
b) Time of human generated aerosols lasting in different environments and its characterization of environmental factors in high-risk settings (e.g., long-term care facilities, dental offices, bars, restaurants, and schools);
c) Effect of temperature, humidity, and sunlight on stability of the virus in actual respiratory secretions
d) Characteristics of optimal face covering, to support source control
e) Better understanding of effective face covering strategies in different environments ***still in need for future research***.

4. WHAT BEHAVIORAL AND ENVIRONMENTAL FACTORS DETERMINE PERSONAL EXPOSURE TO AIRBORNE SARS-COV-2?

Exposure to infectious aerosols and droplets can be influenced by human behaviours, characteristics of the built environment, interventions intended to mitigate exposure risk, and other factors.

At longer-range distances (>1.5 meters), smaller aerosols that can remain airborne for longer time periods dominate exposure.

Indoor environments have been associated with infection events, including outbreaks and super-spreader events. Crowded, indoor, poorly ventilated areas can be conducive to accumulation of aerosols laden with virus.

Masks (face coverings) reduce both emissions and intake of aerosols and droplets by the wearer.

Ways in which ventilation can reduce room-based exposure:

a) ***Ventilation*** should be based on occupancy of the indoor space and there is no "one-size-fits-all" rate to eliminate exposure risk.
   - The American Society of Heating, Refrigerating and Air-Conditioning Engineers recommends **6.7 L/s per person** for school classrooms **(ASHRAE 2003**).
   - On the contrary, other studies have suggested much higher ventilation rates. Outdoor air supply rates of <25 L/s per person increase the risk of sick building

syndrome symptoms, increase short-term sick leave, and decrease productivity (Wargocki et al. 2002).

b) ***Filtration*** is an effective supplement to ventilation for reducing aerosol concentrations indoors.
   - When using filtration technologies, it is critical that the clean air delivery rate is sized to accommodate the room volume, accounting for existing ventilation. But more research is needed on where to place air cleaners to be most effective given typical air flow patterns. Still, there is a need for research, to study how to best upgrade filtration efficiency in existing heating, ventilation, and air conditioning (HVAC) systems.

BOX 3 Measures Used for Ventilation and Filtration Systems

Ventilation Rate is the volume of outside air added to a space per unit time per occupant, typically measured in L/s/person.

Air Change Rate is a measure of the outside air volume added to a space divided by the volume of that space.

High Efficiency Particulate Air filters are a type of mechanical air filter that can theoretically remove at least[a] 99.97% of dust, pollen, mold, bacteria, and aerosol particles.

Minimum Efficiency Reporting Value (MERV) is a rating derived from a test method developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers. The higher the MERV rating the better the filter is at trapping.

Clear Air Delivery Rate is the effective rate (volume per unit time) of filtered air produced by a filtration device.

[a]"The diameter specification of 0.3 microns responds to the worst case; the most penetrating particle size. Particles that are larger or smaller are trapped with even higher efficiency." See https://www.epa.gov/indoor-air-quality-iaq/what-hepa-filter-1.

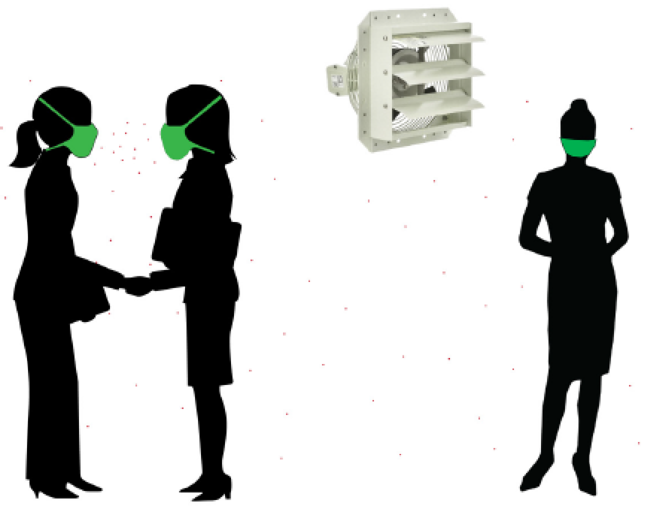
Note: Different measures of the effectiveness of filtration systems that have been developed. From "Airborne Transmission of SARS-CoV-2: Proceedings of a Workshop in Brief", by National Academies of Sciences, Engineering, and Medicine,2020, Washington, DC: The National Academies Press, p.10 (https://doi.org/10.17226/25958). Copyright 2020 by National Academy of Sciences.

c) **Germicidal ultraviolet (UV-C) light** can be useful in environments where it is otherwise challenging to ventilate or filter.
   - It must be applied in a way that does not directly expose humans to it. And additional research is needed to determine the best germicidal UV design for specific spaces.

d) **The essential importance of layered interventions.**
   - Multiple preventive actions to effectively minimise the risk are hand hygiene, distancing, wearing masks indoors, ventilation, and filtration.

5. WHAT DO WE KNOW ABOUT THE INFECTIOUS DOSE AND DISEASE RELATIONSHIP FOR AIRBORNE SARS-COV-2?

Mostly the discussions were focused on indoor environments in which the risk of exposure to SARSCoV-2 is greatest.



- **Source control:** Source control can greatly reduce, if not completely eliminate, the number of aerosols released into the air
- **Ventilation/filtration:** With effective ventilation/filtration, the number of viral aerosols can be greatly reduced
- **Distance and personal protective equipment:** These interventions can offer some protection by reducing a person's exposure
- **Hygiene:** Research indicates that the highest viral loads or positive samples can be found on the floor. Cleaning the floor can reduce the possibility of resuspension

Note: This figure was described by Marr (2020), and it summarized four general categories of interventions and their potential impact on significant reduction in the risk of airborne transmission of SARS-CoV-2. From "Airborne Transmission of SARS-CoV-2: Proceedings of a Workshop in Brief", by *National Academies of Sciences, Engineering, and Medicine,2020, Washington, DC: The National Academies Press*, p.3 (https://doi.org/10.17226/25958). Copyright 2020 by National Academy of Sciences.